PG&E

CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

2005 CEC Title 24 Building Energy Efficiency Standards Rulemaking Proceeding
November 1st, 2003

Excerpts from

Revisions to Proposed
Updates to Title 24 Treatment of Skylights:

- ***Definition of Skylit Zone (§131(c))***
- ***Definitions of Effective Aperture and Well Efficiency (§146(a)4F)***
- ***Requirements for Automatic Multi-Level Daylighting Controls(§119(h) & (i))***
- ***Revised Power Adjustment Factors (§146(a)4F)***
- ***Mandatory Automatic Controls under Skylights (§131(c))***
- ***Skylighting as Base Case for Large Low-Rise Nonresidential Buildings (§143(c))***

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Preface

The Codes and Standards Enhancement (CASE) initiatives present recommendations to support including or upgrading requirements for various technologies in California's Building Energy Efficiency Standards. Pacific Gas and Electric Company sponsored this effort. The program goal is to prepare and submit proposals that will result in valuable, cost-effective enhancements to energy efficiency in buildings. This report, Updates to Title 24 Treatment of Skylights, is one of several nonresidential proposals now included in the draft 2005 Building Energy Efficiency Standards.

The 2005 Standards Update process followed the timeline as show in Figure 1.

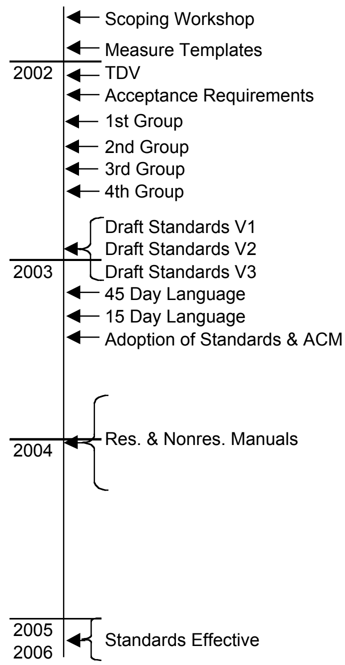

Figure 1 - Standards Process Timeline

In 2001, PG&E program managers and their subcontractor began having discussions about likely candidate opportunities and priorities. Short and long-term planning and strategy sessions were held. Coordination efforts also began with the California Energy Commission (Commission) to lay the groundwork for acceptance of the proposals into the Standards.

In the fall of 2001, PG&E Codes and Standards team members presented their ideas for code changes and ranked them based on energy savings potential, technical feasibility, and market readiness. The top proposals were funded for further research. The technical leads prepared detailed proposals; including cost effectiveness analysis and draft code language, and submitted them at workshops held at the Commission in the spring and summer of 2002. All but three of the proposals were incorporated into the Standards drafts. The PG&E team worked closely with the Commission team to coordinate issues with related proposals. PG&E and its consultants participated in all events leading up to the Standards, and prepared presentations and answered stakeholder questions regarding the proposals.

Executive Summary

Original Proposal

This CASE initiative seeks to incorporate skylighting and automatic daylighting controls as code requirements for large low rise nonresidential buildings. This code proposal would shift the emphasis of Title 24's treatment of skylights from a building feature that is accommodated by the standards to an efficiency measure that is actively promoted by the standards. The proposal seeks to make the following changes to Title 24:

- Modifying the description of the daylit area under skylights to reduce "spacing criterion" from 2.0 to 1.4. This definition would improve lighting uniformity as this definition gives incentive to space skylights closer together.

- Correcting errors in the definitions of effective aperture and well efficiency with definitions based on the ninth edition of the Illuminating Engineering Society of North America (IESNA) Handbook.

- Adding requirements for Automatic Daylighting Control Devices so that they are easy to adjust initially and over time.

- Adding a mandatory requirement that light fixtures in the daylit area under skylights be controlled by a muti-level photocontrol or astronomical time clock whenever the daylit area in a given room is greater than 2,500 square feet. – This requirement assures that lighting energy is saved when most skylighting systems are installed.

- Revising the Power Adjustment Factor (PAF in Table 146 - A) to give more appropriate credit to automatic daylighting controls under skylights. This credit is given only to skylighting systems with diffusing skylights or a diffusing element because non-diffusing skylights would not provide the desired distribution of light compatible with replacing electric lighting.

- Adding a prescriptive requirement for low-rise nonresidential buildings with enclosed areas directly under a roof larger than 25,000 square feet and ceiling heights greater than 15 feet. Such enclosed areas would be prescriptively required to have a minimum amount of skylight area. As the new prescriptive requirement for these spaces, skylighting also would be incorporated into the Standard Design (base case) of the alternate compliance method (ACM).

Several of the measures in this proposal are interrelated:

- The power adjustment factors for photocontrols would be cut in half because the minimum mandatory requirement for daylit zones under skylights, multi-level astronomical time clocks, already save approximately 50% of the savings of photocontrols as compared to no lighting controls. The calculated savings from photocontrols is based on a multi-level system as there is a mandatory requirement for multi-level daylighting controls under skylights.

- The redefined effective aperture would be used to calculate the power adjustment factor which will impact exceptions from the mandatory daylighting controls requirement.

Evolution of Requirements

Recent changes to this proposal include:

- More specific definitions of multi-level astronomical time clocks

- Reintroducing of the option of effective aperture to the minimum skylight area requirements.

- Introducing an intermediate lighting power density criteria with less restrictive minimum skylight area requirements

Astronomical time clocks

Standard time clocks control loads (lighting sprinklers etc.) based upon the time of day. In the past, standard time clocks have been used to turn on and off outdoor lighting. This has been a problem as the sun rises and sets at different times of day depending upon the day of year. Either the user has to reset the on and off times several times per year or the outdoor lights are on during the day or turning on well past sunset. Astronomical time clocks solve this problem by calculating the sunrise and sunset times based upon the latitude and longitude and day of year. Astronomical time clocks control loads based upon the sunrise and sunset times with an offset of so many minutes before of after sunrise or sunset. A typical use of an astronomical time clock is to turn on outdoor lighting 10 minutes after sunset each day. Since the astronomical time clock is calculating the sunset time, this is easily accomplished without having to reset the time clock. For many years, Title 24 has required that outdoor lighting be controlled by a photocontrol or an astronomical time clock.

We have proposed that astronomical time clocks now be allowed for automatic control of electric lighting in response to daylight availability in building interiors. When there is more than 2,500 sf of daylit area under skylights, it is cost-effective to require daylighting controls. In general this requirement is most easily satisfied by the use of a multi-level photocontrol system that turns off or dims lighting in response to available daylight in the building interior. Multi-level controls are required because they save substantially more energy than single level controls while incurring only a small incremental cost for the additional level of control. However, the number of electrical engineers that have designed lighting systems with photocontrols or electrical contractors that have installed photocontrols systems is fairly small. As an intermediary step, while designers and contractors get used to using photocontrols, it was concluded that multi-level astronomical time clocks would be an acceptable alternative to multi-level photocontrol systems. Most electrical engineers and electricians have specified and installed time clocks and are more comfortable with this technology. In addition once all the lighting equipment has been configured for daylighting control, upgrading to photocontrol based system at a later date would be relatively easy. Thus, multi-level astronomical time clocks were included as a method of complying with the automatic daylighting control requirements in Section 131(c).

Much of the language which defines an acceptable control in Section 119(h) “Multi-level Astronomical Time Switch Control”, comes from a letter from Ed Gray of NEMA dated July 16, 2002. One difference is that the NEMA letter suggested that the astronomical time clock have offsets between 1 and 120 minutes whereas the language we have proposed for this section requires an offset of 1 to 240 minutes. Cheryl English of Acuity brands has also recommended the 120 minute limit instead of 240 minutes due to greater product availability.

Astronomical time clocks can be a feature of an EMS system where sunrise and sunset times are calculated and any offset can be programmed into the system. Thus the 240 minute offset time is not a problem for larger EMS-based astronomical time clock controls. The concern raised by Cheryl English is for smaller stand alone systems where the offset time is limited; we are aware that for some stand-alone systems the offset is limited to 99 minutes.

The primary question is: can an astronomical time clock with only 120 minutes of offset provide the needed level of control required of a multi-level system? As required by section 131 – a multi-level system must have, “at least one control step that is between 50% and 70% of design lighting power and at least one step of minimum light output operating at less than 35% of full rated lighting system power (this control step could be completely off, creating a bi-level control).” Thus at the very least, daylight must provide at least 65% of the design illuminance before the last stage of lights can be turned off.

Effective Aperture = 1.20%, Skylight to Floor Ratio (SFR) = 4.10%

Average daylight footcandles (fc)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan	0	0	0	0	0	0	0	1	7	15	26	33	36	31	22	11	4	0	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	3	11	23	38	44	46	44	36	22	9	3	0	0	0	0	0	0
Mar	0	0	0	0	0	0	2	7	20	34	45	53	56	53	47	33	16	5	0	0	0	0	0	0
Apr	0	0	0	0	0	1	5	16	36	52	63	70	72	67	56	44	23	9	2	0	0	0	0	0
May	0	0	0	0	0	[illegible]	[illegible]	26	45	60	71	78	79	74	67	50	31	14	4	0	0	0	0	0
Jun	0	0	0	0	0	3	11	26	44	60	74	82	85	82	71	57	37	18	6	0	0	0	0	0
Jul	0	0	0	0	0	2	9	25	46	65	78	88	90	86	76	60	40	19	7	1	0	0	0	0
Aug	0	0	0	0	0	1	6	18	37	54	71	80	84	81	68	51	31	13	4	0	0	0	0	0
Sep	0	0	0	0	0	0	3	13	33	51	67	74	76	71	58	40	18	6	1	0	0	0	0	0
Oct	0	0	0	0	0	0	2	8	23	37	51	55	56	50	37	21	8	2	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0	4	12	23	34	39	38	33	21	10	3	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	2	6	15	28	32	31	26	17	9	2	0	0	0	0	0	0	0

3 hours

Design Illuminance = 65 fc

< 6.5 fc; < 32.5 fc; < 65 fc; > 65 fc;

Figure 2: Annual illuminance plot with rings illustrating times of 1/3 and 2/3 lights off stages

Figure 2 contains the monthly average illuminances by hour for a typical big box retail store in San Francisco. The outer ring indicates when 1/3 of the lights can be turned off (daylight levels are above 21 foot-candles) and the inner ring when 2/3's of the lights can be turned off (daylight above 42 foot-candles). What can be readily seen is that 2/3's of the lights can be switched off 3 hours (180 minutes) after sunrise. Skylighting systems with less skylights would require more than 3 hours after sunrise before the second stage of lights could be turned off. The requirement of 4 hours after sunrise allows turnoff of the electrical lighting to be delayed until the skylighting system is transmitting the amount of illumination that is needed. The bottom line is that a 120 minute offset will not provide the needed time delay after sunrise to provide adequate daylight to enable the skylighting system to serve its intended function. The concern is that if the second stage is unable to turn off lights at the correct time, this stage of control will be overridden and the savings not realized. If multi-level astronomical time clocks are to be an alternative to photocontrols they must have the capability to turn lights on and off at the appropriate times.

Section 143(c) Minimum Effective Aperture Option

Section 143(c) prescriptively requires a minimum skylight area to daylit area ratio in large open spaces with high ceilings such as warehouses and big box retail spaces. The skylight proposal was initially developed with effective aperture in mind because effective aperture considers all components of the skylighting system (skylight, light well, diffusers etc.) to determine how much light is transmitted by the skylighting system. As the proposal was developed, it was concluded that calculating effective aperture might be too complex for routine skylighting applications and would be harder to enforce. As a result, the initial proposal was simplified to define the acceptable skylight area based only on minimum skylight to roof area ratio. However, some skylight manufacturers have been concerned that this standard did not give enough credit to skylighting systems that were highly transmitting and yet met the diffusion requirements. Thus minimum effective aperture was added back in as an alternative method of showing compliance with the minimum skylight area requirement in Section 143(c).

When the proposal was initially developed it was based upon 4 warehouse models and 1 retail model. The four warehouse models considered unconditioned and conditioned warehouses with lighting power densities of 0.7 and 1 W/sf. The retail model was based upon a 1.6 W/sf general lighting power density. These models were the basis of the earlier minimum skylight areas.

Since that time the Heschong Mahone Group has surveyed skylit buildings with photocontrols on behalf of Southern California Edison.[1] Figure 3 plots and fits a trend line through surveyed data of skylight to floor area ratio as a function of the lighting power density of the general lighting in warehouse and big box retail stores. This survey revealed that a significant number of big box retailers have general lighting power densities around 1.25 W/sf. In addition common practice for these spaces is to install a skylight area that is around 3.3% of the daylit floor area. Given that the requirement is for a statewide minimum skylight to daylit area ratio, loosening the standard slightly from 3.6% to 3.3% appears to be reasonable for buildings with lighting power densities between 1.0 and 1.4 W/sf.

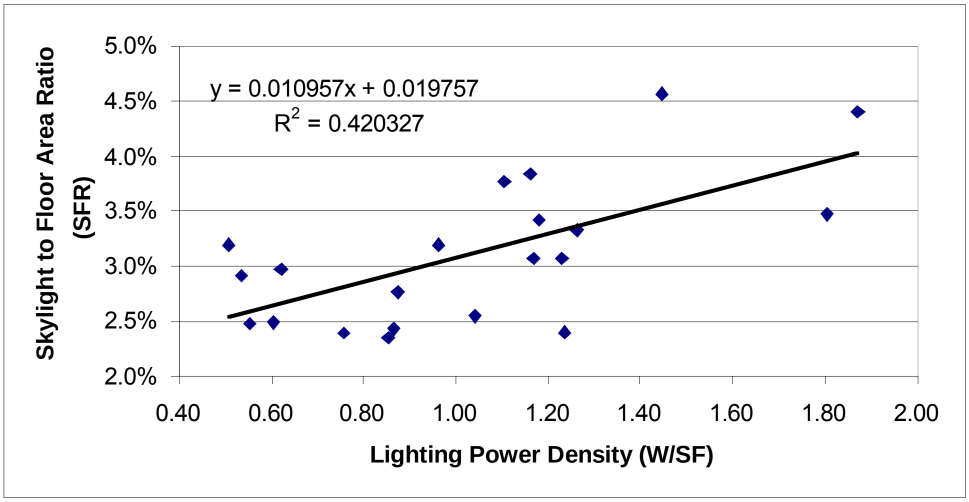

Figure 3: Comparison of Skylight to Floor Area Ratio to Lighting Power Density in Warehouses and Retail

It should be noted that retail spaces with higher LPD's typically had skylight to floor area ratios of 4%. These standards for minimum skylight area for these spaces are conservatively low. This is reasonable as the optimal amount of skylight area depends upon a number of design factors. However, the nonresidential manual should emphasize that these minimum areas are just that, minimums, and in most cases the optimum skylight area is higher.

Energy Savings

The statewide impact of this code proposal after 10 years of new nonresidential construction with skylighting and photocontrols is 230 Gigawatt-hours per year of energy savings, 40 Megawatts of electrical demand savings coincident with utility system peak, and 1 Million therms of additional natural gas consumption. When the cost of additional natural gas consumption is subtracted from the electricity savings, the discounted life cycle (3% discount rate, 15 year period of analysis) energy cost savings of this 10 years of new skylit buildings will save California businesses approximately $330 Million in utility costs.

[1] Heschong Mahone Group, Photocontrol System Field Study, Report for Southern California Edison, 2003

Proposed Language

Building Energy Efficiency Standards

Section 101

Section 101 was been revised and updated to incorporate the changes in definitions proposed. In addition many of the definitions are contained in the actual standards language. For instance the definitions of well efficiency is no longer contained in the Definitions section but rather in Section 146 and the daylit area definition directs readers to the appropriate section of the standard where the definition is incorporated into the daylighting controls requirements in Section 131(c).

DAYLIT AREA is the floor area that is illuminated by daylight through vertical glazing or skylights as specified in Section 131 (c). ~~is the space on the floor that is the larger of 1 plus 2, or 3;~~

1. ~~For areas daylit by vertical glazing, the daylit area has a length of 15 feet, or the distance on the floor, perpendicular to the glazing, to the nearest 60-inch or higher opaque partition, whichever is less; and a width of the window plus either 2 feet on each side, the distance to an opaque partition, or one half the distance to the closest skylight or vertical glazing, whichever is least.~~
2. ~~For areas daylit by horizontal glazing, the daylit area is the footprint of the skylight plus, in each of the lateral and longitudinal dimensions of the skylight, the lesser of the floor-to-ceiling height, the distance to the nearest 60-inch or higher opaque partition, or one half the horizontal distance to the edge of the closest skylight or vertical glazing.~~
3. ~~The daylit area calculated using a method approved by the commission.~~

EFFECTIVE APERTURE (EA) is the extent that vertical glazing or skylights are effective for providing daylighting. The effective aperture for vertical glazing is specified in Exception 1 to Section 131 (c). The effective aperture for skylights is specified in Section 146 (a) 4 E. ~~is (1) for windows, the visible light transmittance (VLT) times the window wall ratio; and (2) for skylights, the well index times the VLT times the skylight area times 0.85 divided by the gross exterior roof area.~~

~~**EFFICACY** is the ratio of light from a lamp to the electrical power consumed (including ballast losses), expressed in lumens per watt.~~

SKYLIGHT is glazing having a slope less than 60 degrees from the horizontal with conditioned or unconditioned space below.

SKYLIGHT AREA ~~is the area of the surface of a skylight, plus the area of the frame, sash, and mullions~~ is the area of the rough opening for the skylight.

~~**WELL INDEX** is the ratio of the amount of visible light leaving a skylight well to the amount of visible light entering the skylight well and is calculated as follows:~~

~~(a) For rectangular wells:~~

$$\left(\frac{\text{Well height}\,(\text{well length}+\text{well width})}{2\times\text{well length}\times\text{well width}}\right);$$

~~**or**~~

~~(b) For irregular-shaped wells:~~

$$\left(\frac{\text{Well height} \times \text{well perimeter}}{4 \times \text{well area}}\right)$$

~~Where the length, width, perimeter, and area are measured at the bottom of the well, and *R* is the weighted average reflectance of the walls of the well.~~

Section 119

Changes from the original proposal included here primarily are in response to suggestions made by the NEMA lighting controls group. These suggestions were very helpful. Of particular note are the exceptions for networked controls in Section 119(e) and much of the requirements in Section 119(h) for multi-level astronomical time clocks.

(e) **Automatic Daylighting Control Devices**. Automatic daylighting control devices used to control lights in daylit zones shall:

1. Be capable of reducing the light output of the general lighting of the controlled area by at least one half in response to the availability of daylight while maintaining relatively~~a~~ uniform illumination ~~level of illuminance~~ throughout the area; and
2. If the device is a dimmer, provide electrical outputs to lamps for reduced flicker operation through the dimming range and without causing premature lamp failure; and
3. If the devices- reduce lighting in control steps~~is a stepped dimming system~~, incorporate time-delay circuits to prevent cycling of light level changes of less than three minutes~~;~~ and~~4. If the device uses step switching with separate on and off settings for the steps,~~ have sufficient separation (deadband) of on and off points for each control step to prevent cycling; and

~~5.Have provided by the manufacturer step-by-step instructions for installation and start-up calibration to design footcandle levels~~

4. If the devices have a time delay, have the capability for the time delay to be over-ridden or set to less than 5 seconds time delay for the purpose of set up and calibration, and automatically restore its time delay settings to normal operation programmed time delays after no more than 60 minutes; and
5. Have a setpoint control that easily distinguishes settings to within 10% of full scale adjustment; and
6. Have a light sensor that has a linear response with 5% accuracy over the range of illuminances measured by the light sensor; and
7. If the device is a stepped switching control device, show the status of lights in the controlled zone by an indicator on the control device; and
8. If the device is a dimming control device, display the light level measured by the light sensor, if the controlled electric lighting cannot be viewed from where setpoint adjustments are made.

   EXCEPTION to Section 119(e) 7 & 8: If the control device is part of a networked system with a central display of each control zone status, the status indicator or light level display on each individual control device shall not be required if control setpoint adjustments can be made at the central display.

(f) **Interior ~~Photocell Sensor Devices~~Photosensors**. Interior photosensor~~photocell sensors~~ shall not have a mechanical slide cover or other device that permits easy unauthorized disabling of the control, and shall not be incorporated into a wall-mounted occupant-~~sensing device~~sensor.

(h) **Multi-level Astronomical Time-switch Controls.** Multi-level astronomical time-switch controls used to control lighting in daylit zones shall:

1. Contain at least 2 separately programmable steps (relays) per zone that reduces illuminance in a relatively uniform manner as specified in Section 131(b); and
2. Have a separate offset control for each step of 1 to 240 minutes; and

3. Have sunrise and sunset prediction accuracy within +/- 15 minutes and timekeeping accuracy within 5 minutes per year; and

4. Store time zone, longitude and latitude in non-volatile memory; and

5. Display date/time, sunrise and sunset, and switching times for each step; and

6. Have an automatic daylight savings time adjustment; and

7. Have automatic time switch capabilities specified in Section 119 (c).

(i) **Automatic Multi-Level Daylighting Controls.** An automatic multi-level daylighting control used to control lighting in daylit zones shall:

1. Meet all the requirements of section 119 (e) for automatic daylighting control devices; and

2. Meet all the multi-level and uniformity requirements of section 131 (b); and

3. Have a light sensor that is physically separated from where setpoint adjustments are made; and

4. Have controls for calibration adjustments to the lighting control device that are readily accessible to authorized personnel.

Section 131(b)

(b) **Multi-Level Lighting Controls~~Controls to Reduce Lighting~~**. The general lighting of any enclosed space 100 square feet or larger in which the connected lighting load exceeds 0.8watts per square foot~~ for the space as a whole~~, and that has more than one light source (luminaire), shall ~~be controlled so that the load for the lights may be reduced by at least one half while maintaining a reasonably uniform level of illuminance throughout the area~~ have multi-level lighting controls. ~~A reasonably uniform reduction of illuminance shall be achieved by:~~ A multi-level lighting control is a lighting control that reduces lighting power by either continuous dimming, stepped dimming, or stepped switching while maintaining a reasonably uniform level of illuminance throughout the area controlled. Multilevel controls shall have at least one control step that is between 50% and 70% of design lighting power and at least one step of minimum light output operating at less than 35% of full rated lighting system power (this control step could be completely off, creating a bi-level control). A reasonably uniform level of illuminance in an area shall be achieved by any of the following:

1. Dimming all lamps or luminaires; or

2. Switching alternate lamps in luminaires, alternate luminaires, and alternate rows of luminaires.

~~1. Controlling all lamps or luminaires with dimmers; or~~

~~2.Dual switching of alternate rows of luminaires, alternate luminaires, or alternate lamps; or~~

~~3.Switching the middle lamps of three lamp luminaires independently of the outer lamps; or~~

~~4.Switching each luminaire or each lamp.~~

EXCEPTION to Section 131 (b): Lights in corridors.

Section 131(c)

(c) **Daylit Areas**. Luminaires providing general lighting that are in or are partially in the daylit area shall be controlled according to the applicable requirements in items 1 and 2 below. The daylit area under skylights shall be the rough opening of the skylight plus, in each of the lateral and longitudinal dimensions of the skylight, the lesser of 70% of the floor-to-ceiling height, the distance to the nearest 60-inch or higher permanent partition, or one half the horizontal distance to the edge of the closest skylight or vertical glazing. The daylit area illuminated by vertical glazing shall be the daylit depth multiplied by the daylit width, where the daylit depth is 15 feet, or the distance on the floor, perpendicular to the glazing, to the nearest 60-inch or higher permanent partition, whichever is less; and the daylit width is the width of the window plus, on each side, either 2 feet, the distance to a permanent partition, or one half the distance to the closest skylight or vertical glazing, whichever is least. ~~Daylit areas in any enclosed space greater than 250 square feet shall meet the requirements of Items 1 and 2 below~~

~~1. Such areas shall have at least one control that:~~

~~A. Controls only luminaires in the daylit area; and~~

~~B. Controls at least 50 percent of the lamps or luminaires in the daylit area, in a manner described in Section 131 (b) 1 through 4, independently of all other lamps or luminaires in the enclosed space. The other luminaires in the enclosed space may be controlled in any manner allowed by Section 131 (b) 1 through 4.~~

~~2. Such areas shall have controls that control the luminaires in each vertically daylit area separately from the luminaires in each horizontally daylit area.~~

1. Daylit areas greater than 250 square feet in any enclosed space shall have at least one lighting control that:
   - A. Controls at least 50% of the power in the daylit areas separately from other lighting in the enclosed space; and
   - B. Controls luminaires in vertically daylit areas separately from horizontally daylit areas.
   - C. Maintains a reasonably uniform level of illuminance in the daylit area using one of the methods specified in Section 131 (b) items 1 or 2.
2. When the daylit area in any enclosed space is under skylights and has a total area greater than 2,500 square feet, the general lighting in the daylit area under skylights shall be controlled separately by either an automatic multi-level daylighting control that meets the requirements of Section 119 (i) or a multi-level astronomical time switch that meets the requirements of section 119 (h) and has override switches that meet the requirements of section 131 (d) 2.

EXCEPTIONS to Section 131 (c)

1. **~~EXCEPTION 1 to 131 (c):~~** Daylit areas where the effective aperture ~~of glazing~~ is less than 0.1 for vertical glazing and less than 0.006 ~~0.01~~ for ~~horizontal glazing~~skylights. The effective aperture for vertical glazing is the visible light transmittance (VLT) times the window wall ratio. The effective aperture for skylights is specified in Section 146 (a) 4 E.
2. **~~EXCEPTION 2 to 131 (c):~~** Daylit areas where existing adjacent structures or natural objects obstruct daylight to the extent that effective use of daylighting is not feasible.

Section 143(c)

This section was reordered so that all of the skylight requirements are grouped together before discussing the controls requirements. Language was removed about automatic daylighting controls, as the intent of this item is that lighting be controlled as described in Section 131(c) which would allow either a photocontrol or an astronomical time clock.

(c) **Minimum Skylight Area for Large Enclosed Spaces in Low-Rise Buildings.** Low rise conditioned or unconditioned enclosed spaces that are greater than 25,000 ft^2 directly under a roof with ceiling heights greater than 15 ft and have a lighting power density for general lighting equal to or greater than 0.5 W/ft^2 shall meet sections 143 (c) 1-4 below:

1. **Daylit Area.** At least one half of the floor area shall be in the daylit ~~zone~~ area under skylights.
2. ~~**Controls.** Electric lighting in the daylit area shall be controlled with multi-level automatic daylighting controls as described in Section 131 (c) 2.~~

2. ~~3~~ **Minimum Skylight Area or Effective Aperture.** Areas that are daylit shall have a minimum skylight area to daylit ~~zone~~ area ratio or minimum skylight effective aperture as shown in TABLE 143-F. Skylight effective aperture shall be determined as specified in Equation 146-A.

3. ~~4~~ **Skylight Characteristics.** Skylights shall:

A. Have a glazing material or diffuser that has a measured haze value greater than 90%, tested according to ASTM D1003 (notwithstanding its scope) or other test method approved by the Commission; and

B. If the space is conditioned, meet the requirements in Section 143 (a) 6 or 143 (b).

4. **Controls.** Electric lighting in the daylit area shall be controlled as described in Section 131 (c) 2.

EXCEPTION 1 to Section 143 (c): Buildings in climate zones 1 or 16.

EXCEPTION 2 to Section 143 (c): Auditoriums, movie theaters, museums, and refrigerated warehouses.

TABLE 143-F MINIMUM SKYLIGHT AREA TO DAYLIT FLOOR AREA OR MINIMUM SKYLIGHT EFFECTIVE APERTURE IN LOW-RISE ENCLOSED SPACES >25,000 FT² DIRECTLY UNDER A ROOF

General Lighting Power Density in ~~the~~ Daylit Areas ~~Zone~~ (W/ft²)	Minimum Skylight Area to Daylit ~~Zone~~ Area Ratio	Minimum Skylight Effective Aperture
1.4~~0~~ W/ft² ≤ LPD	3.6%	1.2%
1.0 W/ft² ≤ LPD < 1.4	3.3	1.1%
0.5 W/ft² ≤ LPD < 1.0 W/ft²	3.0%	1.0%

Section 146(a)4E

Glazing transmittance is updated to include any element in the skylighting system (other than the light well) that reduces light transmittance. Glazing transmittance redefined to include the impact of louvers, diffusers etc. With such a revised definition the effective aperture closely approximates the fraction of outdoor luminous flux on the roof that is transmitted by the skylighting system.

4. **Reduction of wattage through controls.** The controlled watts of any luminaire ~~that is controlled~~ may be reduced by the number of controlled watts times the applicable factor from TABLE 146-A~~Table 1-L~~ if:

~~D.~~E. For daylighting control credits, the luminaire is controlled by the daylighting control, and the luminaire is located within the daylit area. The power adjustment factor is a function of the lighting power density of the general lighting in the space and the effective aperture of the skylights determined using Equation 146-A.

EQUATION 146-A – EFFECTIVE APERTURE OF SKYLIGHTS

$$\text{Effective Aperture} = \frac{0.85 \times \text{Total Skylight Area} \times \text{Glazing Visible Light Transmittance} \times \text{Well Efficiency}}{\text{Daylit Area Under Skylights}}$$

Total skylight area is the sum of skylight areas above the space. The skylight area is defined as the rough opening of the skylight.

Glazing visible light transmitance is the ratio of visible light that is transmitted through a glazing material to the light that is incident on the material. This shall include all skylighting system accessories including diffusers, louvers etc. The visible light transmittance of movable accessories shall be rated in the full open position. When the visible light transmittance of glazing and accessories are rated separately, the overall glazing transmittance is the product of the visible light transmittances of the glazings and accessories.

Daylight area under skylights is as defined in Section 131(c).

Well Efficiency is the ratio of the amount of visible light leaving a skylight well to the amount of visible light entering the skylight well and shall be determined from the nomograph in FIGURE 146-A based on the weighted average reflectance of the walls of the well and the well cavity ratio (WCR), or other test method approved by the Commission.

The well cavity ratio (WCR) is determined by the geometry of the skylight well and shall be determined using either Equation 146-B or Equation 146-C.

EQUATION 146-B WELL CAVITY RATIO FOR RECTANGULAR WELLS

$$\mathrm{WCR} = \left(\frac{5 \times \text{well height}\,(\text{well length} + \text{well width})}{\text{well length} \times \text{well width}} \right)$$ **;or**

EQUATION 146-C WELL CAVITY RATIO FOR NON-RECTANGULAR-SHAPED WELLS:

$$\mathrm{WCR} = \left(\frac{2.5 \times \text{well height} \times \text{well perimeter}}{\text{well area}} \right)$$

Where the length, width, perimeter, and area are measured at the bottom of the well.

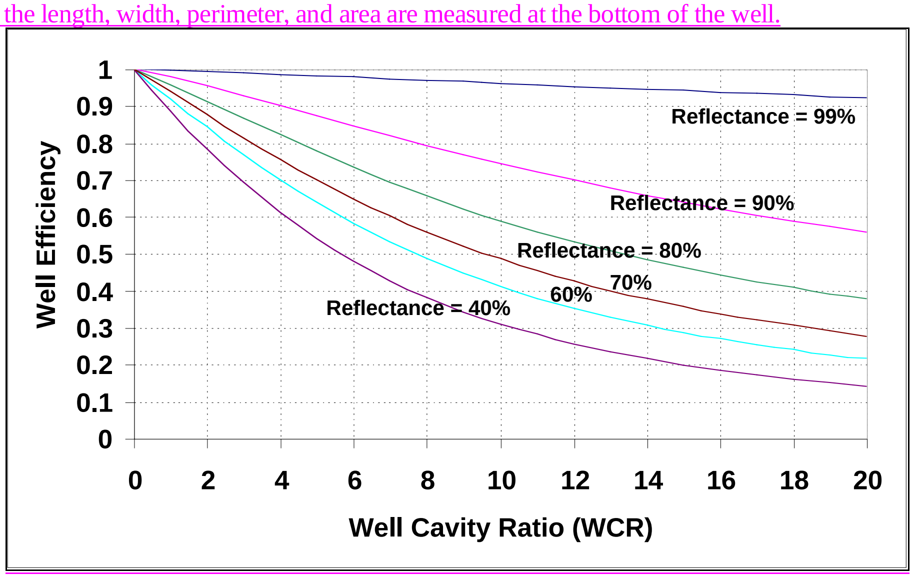

FIGURE 146-A WELL EFFICIENCY NOMOGRAPH

TABLE 146-A~~L —~~ LIGHTING POWER ADJUSTMENT FACTORS

TYPE OF CONTROL	TYPE OF SPACE	FACTOR
Automatic Multi-Level Daylighting Controls with Skylights		
Glazing Type - Skylights	Factor	
Glazing material or diffuser with ASTM D1003 haze measurement greater than 90%	$10 \times \text{Effective Aperture} - \frac{\text{Lighting Power Density}}{10} + 0.2$ WHERE Effective Aperture is as calculated in the Equation 146-A. Lighting Power Density is the lighting power density of general lighting	
x		

Alternate Calculation Manual

Only changes made to the ACM regarded the three LPD tiers for minimum effective aperture associated with buildings that are subject to Section 143(c).

Energy Savings Estimates

A detailed disaggregation of the Energy Impacts analysis found that the first year's implementation of the skylighting requirements would reduce electricity energy consumption by 23 Gigawatt/hr per year, reduce electrical demand coincident with utility system peak by 4 Megawatts, and increase natural gas consumption by 100,000 therms/yr. The discounted life cycle energy cost savings (3% discount rate, 15 year period) is $35 Million for one year's new construction. . After 10 years of this code measure the savings would be approximately tenfold or about $350 Million of energy savings that accrue over the life of these buildings.

This estimate was based upon a DOE-2 thermal and daylighting simulation of the 990 buildings in the Nonresidential New Construction database and expanded up to the population of one year's new construction which is estimated to be 157 Million square feet per year for all building types. This analysis applied skylights and stepped photocontrols to one half of the area of those spaces that were over 25,000 sf and had ceiling heights greater than 15 ft.

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The photometrics used for analysis was developed as a part of the Integrated Energy Systems Productivity and Building Science PIER project sponsored by the California Energy Commission with Cathy Higgins as the program director and Donald Aumann as the CEC project manager for the NBI PIER project. *SkyCalc* tool used to calculate appropriate Power Adjustment Factors was developed by Heschong Mahone Group, Inc. for Southern California Edison and is part of the Energy Design Resources suite of efficient building design tools. Skylight survey data was gathered as part of a photocontrol effectiveness study commissioned by Southern California Edison.

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